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Tribological characterization of rail squat defects

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ABSTRACT

Rail squats remain a major rolling contact fatigue problem for mass transit authorities. Several studies have been conducted to supplement the standard characterization of rail squats. In particular an extensive tribological and metallurgical investigation was performed on samples of incipient squats from various areas. Surfaces and cross-sections of rail samples were observed by optical microscopy and scanning electron microscopy. These observations highlighted that the running band is composed of longitudinal contact strips with various surface and subsurface morphologies. This microstructure seems to be essential for the onset of squats. This new information makes it possible to account for the entire damage mechanism of a squat defect from initiation to propagation.

1. Introduction

The well-developed form of squats is identified in the International Union of Railways (UIC) rail defects catalogue [1] as a light depression and widening of the rail tread along with a blackish spot and two V-shape cracks, as shown in Fig. 1.

Squats have recently become recognised as one of the major rolling contact fatigue defects in modern railway networks for which there is currently no solution other than preventive grinding operations [2] or costly rail renewal. Consequently, many studies have been performed to understand the mechanisms by which rail squats are initiated and propagated.

Squats were first detected in Japanese railway networks in the 1950s [3,4]. Its initiation mechanism is often associated with plastic flow and rolling contact fatigue. The same observations were made when squats were finally detected in European tracks in the 1970s [3,5], after years of unsuitable classification. It was assumed that crack initiation resulted from the accumulation of plastic deformation leading to the fracture of the pearlite. In 1982, Clayton and Allery [6] presented the results of a research programme performed with British Railways. Maximum observable shear and hardness was measured at the surface of the rail and the early stage of squats was identified as a surface micro-crack on the gauge corner side, at the edge of the bright running band, as shown in Fig. 2.

More recently, other studies [7–9] have confirmed that microstructure deformation could be a major factor influencing rolling contact fatigue (RCF) crack initiation. In addition, calculations of stresses in the rail subjected to repeated moving contacts were performed [10,11] and showed crack initiation must take place near the surface of the running band in the case of squats.

In the 1990s, studies on squats were mainly focused on crack growth using 2D models. According to Clayton [12] and Bold [13] the growth of squat-type cracks takes place in two steps, with surface initiated cracks propagating downwards at a shallow angle to a critical depth of a few millimetres before branching down into the bulk material. Later, a European rolling contact fatigue research program was carried out [14]. Focusing on squats in particular, Bogdański [15,16] studied the influence of various contact conditions on the values of the stress intensity factors at the crack front. He modelled incipient squat as a semi-elliptical plane and showed that mixed-mode fatigue crack propagation takes place. In particular the influence of a liquid-entrapment mechanism was analyzed [17,18].

Although the propagation mechanism of an incipient crack stemming from surface deformation seems quite clear, the root causes of this accumulation of microstructural strains are rather controversial and several reasons have been put forward.

The role of tractive forces on the microstructural state of railheads has been discussed in many studies. For example, Kondo [19], Johnson [20], Ishida [21] and Busquet [22] assumed that the shear resulting directly from wheel–rail tractive forces could be the main cause of the surface deformation that initiates squats. The recent increase in the number of squats could be linked to

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the introduction of heavier rolling stock and the need to obtain increasing adherence. This new situation could unbalance the interaction between both fatigue and wear processes and favour a fatigue crack initiation over wear mechanism in some cases.

Conversely, Aknin [23] observed that squats have never been reported on low-speed lines with heavy trains, whereas these are subjected to the highest levels of traction. Thus his work showed, by calculation, that residual stresses in the tread could be explained in some cases by the dynamical behaviour of high speed locomotives with or without traction force.

On the other hand, according to the UIC defects catalogue [1] rail squats are often associated with other geometric defects and Clayton [3] assumed that they could also occur due to indentation, corrugation or spalling of the white etching layer. Li and Dollevoet [24–27] analysed this path in greater depth and introduced small rail top defects in a wheel/rail transient finite element model. They showed that wheel crack interaction and especially dynamic contact forces could lead to the accumulation of plastic deformation and squats growth.

Taken separately these mechanisms could occur at any point in a railway and they do not allow understanding why rail squats develop only in some specific areas according to field investigations on the RATP network and other studies [2,25]. It is likely that several mechanisms occur and combine to initiate squats. All these studies agree that contact conditions must be very unusual and specific in squats areas and that these contact conditions require clarification to understand the entire damage mechanism. The problem is that the data necessary are difficult to obtain. The purpose of the present study is to track these contact conditions from their visible consequences according to laboratory tribological experiments.

To achieve this, samples of rails that had been in service under real traffic conditions were collected and several investigations were carried out:

1. A tribological and metallurgical analysis of the rolling band and the near surface layer was performed close to an incipient squat in order to clarify the contact conditions accompanying defect initiation. The rail surface and cross-section of the rail were observed by microscopy to identify strain direction and depth. The aspect of the white etching layer was also closely inspected.
2. In the case of well-developed squats, the accumulation of plastic deformation observed at the surface does not provide useful information. Consequently, the crack network was studied in two ways. First, test milling of a large sample of rail squats was performed to establish a relation between surface aspect and crack depth. Second, the top of the squat was removed to examine the surface state of crack fronts and deduce the main factors of influence under the surface.

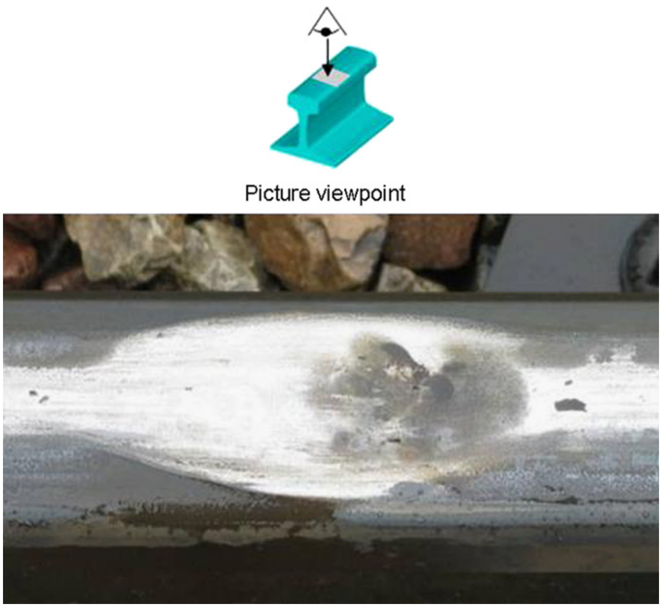

Fig. 1. Well-developed form of a squat defect.

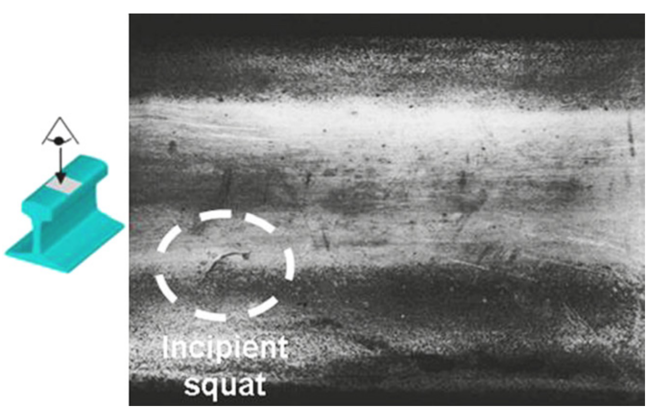

Fig. 2. Incipient form of a squat defect [6].

2. Experimental details

2.1. Sampling sites

In order to draw up a general overview of rail squats in the RATP network, investigations were performed on samples from

Table 1
Characteristics of sampling sites.

		Site 1:	Site 2:	Site 3:	Site 4:	Site 5:
Track data	Rail profile	60E1	60E1	60E1	60E1	60E1
	Steel grade	R260*	R260	R260	R260	R260
	Track geometry	Large radius	Straight line	Straight line	Straight line	Straight line
	Track layer	Ballast	Ballast	Ballast	Ballast	Ballast
	Sleeper-type	Wood	Twin-block	Twin-block	Twin-block	Twin-block
	Last grinding	2009	2006	2009	2008	2009
	Track-laying	2008	2006	2006	2008	2006
Vehicle data	Type**	MI2N/MI84/MS61	MI2N/MI84	MI2N/MI84	MI2N/MI84	MI2N/MI84
	Axle load (T)	18/14/12	18/14	18/14	18/14	18/14
Traffic conditions	Velocity (km/h)	60–70 Braking Area	80–90 Braking area	110–120 Traction area	80–90 Braking area	80–90 Traction area
	Mean load per day (T)	160,000	60,000	60,000	60,000	60,000

* Chemical composition of rail steel R260 (%): C (0.74), Mn (1.08), Si (0.30), P (0.013), S (0.018), Cr (0.040), Al (0.003).
** MI2N: 3 powered cars and 2 unpowered cars MI84: 2 powered cars and 2 unpowered cars MS61: 2 powered cars and 1 unpowered car.